ADA104754

Report SAM-TR-81-23

LEVEL

(12)

FATIGUE IN DOUBLE-CREW AERIAL-REFUELED TRANSPORT MISSIONS

William F. Storm, Ph.D.
Patrick J. Dowd, M.S.
Gerald W. Noga, Colonel, USAF, MC*
*(Office of Aviation Medicine (MAC/SGPA), Scott AFB IL 62225)
Lowell A. Schuknecht, Lieutenant Colonel, USAF, MC**
**(USAF Hospital Mountain Home/SG, Mountain Home AFB ID 83648)

August 1981

Final Report for Period May 1977 - May 1980

USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

NOTICES

This final report was submitted by personnel of the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks Air Force Base, Texas, under job order 7930-10-28.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The operational personnel who participated in this study were fully briefed on all procedures prior to participation in the study.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

William F. Storm

WILLIAM F. STORM, Ph.D.
Project Scientist

Bryce O. Hartman

BRYCE O. HARTMAN, Ph.D.
Supervisor

Roy L. DeHart

ROY L. DEHART
Colonel, USAF, MC
Commander

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

14

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: SAM-TR-81-23

2. GOVT ACCESSION NO.: AD-A104754

3. RECIPIENT'S CATALOG NUMBER:

4. TITLE (and Subtitle): 6 FATIGUE IN DOUBLE-CREW AERIAL-REFUELED TRANSPORT MISSIONS

5. TYPE OF REPORT & PERIOD COVERED: 4 Final Report. May [redacted]977 — May [redacted]980

6. PERFORMING ORG. REPORT NUMBER:

7. AUTHOR(s): 10 William F. Storm[redacted] Patrick J. Dowd, M.S.; Gerald W. Noga[redacted] Lowell A. Schuknecht, ~~Lt Col, USAF, MC**~~

8. CONTRACT OR GRANT NUMBER(s): 17 10

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
USAF School of Aerospace Medicine (VNE)
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 62202F 7930-10-28

11. CONTROLLING OFFICE NAME AND ADDRESS:
USAF School of Aerospace Medicine (VNE)
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas 78235

12. REPORT DATE: 11 Aug[redacted]981

13. NUMBER OF PAGES: 19

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): 12 22

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Gerald W. Noga, Col, USAF, MC
Office of Aviation Medicine (MAC/SGPA)
Scott AFB IL 62225

**Lowell A. Schuknecht, Lt Col, USAF, MC
USAF Hospital Mountain Home/SG
Mountain Home AFB ID 83648

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Blue/Gold
Double crews
C-5A
Subjective fatigue
Sleep
Sleep loss
Work/rest schedule
Airlift
Shift work

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Military Airlift Command (MAC) contingency plans call for extending strategic airlift capability by flying C-5A aircraft with double crews and aerial refueling. This mode of operation is known as the Blue and Gold concept. Standard MAC operations limit the C-5A basic crew-duty day to 16 hours, after which a minimum en route crew-rest/ground time of 16.25 hours is required before flying duty can be resumed. Under the Blue and Gold concept, two crews, one designated Blue and the other Gold, alternate being on duty on the flight deck and off duty in crew rest. The mission progresses as the two crews alternate responsibility

DD FORM 1 JAN 73 1473

217000

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

for the aircraft. Thus, under the Blue/Gold concept, all en route crew rest and sleep occur onboard the aircraft, and much of this time is while the aircraft is airborne. Self-ratings of subjective fatigue and sleep histories were used to evaluate crew fatigue during five Blue/Gold missions, two each of 32 and 56 hours and one of 44 hours. Summarizing the five missions, the fatigue experienced by the crews was closely related to mission schedule. The crews were well rested at the start of each mission, averaging a typical 7-8 hours of sleep per night during a 3-day baseline period. At the end of the 32- and 44-hour missions, the on-duty crews reported more fatigue than the resting crews. At the end of the 56-hour missions, the two crews differed little: both reported moderate to considerable fatigue. Eight of 10 crews reported a 30% or greater increase in hours slept during the first 24 hours of recovery. The subjective fatigue scores and hours of sleep reported after the first day of recovery seldom differed from those reported during the premission baseline period. Considering these and previous findings, double-crew aerial-refueled missions of 40-48 hours are feasible and safe.

PREFACE

While previously assigned to Military Airlift Command (SGPA), Lt Col Schuknecht was responsible for planning and implementing the Blue/Gold biomedical evaluation. At the USAF School of Aerospace Medicine, Sgt Robin G. Chavez (USAFSAM/VNE) systematically organized and reduced the raw data and Mr. Richard C. McNee and Mr. Donald J. Cosgrove (USAFSAM/BRA) directed the statistical analyses.

FATIGUE IN DOUBLE-CREW
AERIAL-REFUELED TRANSPORT MISSIONS

INTRODUCTION

Military Airlift Command (MAC) contingency plans call for extending strategic airlift capability by flying C-5A aircraft with double crews and aerial refueling. This mode of operation is known as the Blue and Gold concept. Standard MAC operations limit the basic crew-duty day to 16 hours, after which a minimum en route crew-rest/ground time of 16.25 hours is required before flying duty can be resumed. This period provides the crew a minimum of 8 hours rest; time for transportation, postflight clearing, and meals; and 3.25 hours for predeparture preparation. Under the Blue and Gold concept, all en route crew rest and sleep occur onboard the aircraft--much of the time while airborne. Two crews, one designated Blue and the other Gold, alternate being on duty on the flight deck and off duty in crew rest. The mission progresses as the two crews alternate responsibilty for the aircraft.

In November 1976, the Commander-in-Chief of MAC instructed the Director of Readiness and Tactics Development (MAC/XON) and the Office of the Command Surgeon (MAC/SG) to conduct a test (MAC Test Plan 15-13-77) of crew capability in the Blue/Gold mode. The Crew Technology Division of the USAF School of Aerospace Medicine (USAFSAM/VN) assisted MAC/SG in evaluating the stress and fatigue experienced by C-5A crews flying double-crew, extended aerial-refueled missions in support of this test. An initial version of this report was published as an annex to the Director of Operational Requirements (MAC/XPQT) Blue and Gold Concept OT&E Final Report (6).

METHOD

The evaluation consisted of six dedicated C-5A missions, two each of 32, 44, and 56 hours duration. The missions started and terminated at home base, either Dover AFB, Delaware (32- and 56-hour missions) or Travis AFB, California (44-hour missions). The 32-hour missions comprised 2 legs and 2 aerial refuelings; the 44-hour missions, 3 legs and 3 aerial refuelings; and the 56-hour missions, 4 legs and 3 aerial refuelings. Two basic crews were assigned to each mission, and each crewmember participated in only one mission. A basic C-5A crew consists of 2 pilots, 1 navigator, 2 flight engineers, and 3-4 loadmasters. Two medical observers flew on each mission. For reasons of safety, an aerial-refueling-qualified flight-examiner crew was onboard at all times to perform observer duties. A fresh flight-examiner crew boarded the mission at the start of each leg.

During the missions, one crew was on duty on the flight deck while the other crew was in crew rest in the aft troop compartment. The crew on duty first was always designated as the Blue crew. The troop compartment was modified by blocking out the windows and improvising crew-rest facilities. The individual facilities were made of a plywood-sheet base, a framework made from

electrical conduit, and curtains draped over this framework. A mattress with a restraining belt and an emergency walkaround oxygen bottle were placed inside the framework. As much as possible, the resting crew did not interact with the on-duty crew. Shift changes between crews occurred at 16-hour intervals, beginning with the time of initial alert. For C-5A operations, crewmen are alerted 3 hours 15 minutes prior to scheduled takeoff. Duty cycles were scheduled as proportionately as possible to allow each crew to perform an equal number of takeoffs, aerial refuelings, approaches, and landings. For this test, the crews were given a minimum of 72 hours premission crew rest and 72 hours postmission crew rest.

Sleep histories and self-ratings of subjective fatigue were used to evaluate crew fatigue. These measures have been used previously by SAM/VN for evaluating flying personnel in various operations (2-5). The Sleep Survey (SAM Form 154, Fig. 1) documents the total hours of sleep during each 24 hours. The Subjective Fatigue Checkcard (SAM Form 136, Fig. 2) yields a score from 0-20 (arbitrary units), with lower scores indicating greater fatigue (7). In general, fatigue scores of 12 or higher have been found to indicate feelings of alertness, scores from 11 down to 8 suggest moderate fatigue, and scores of 7 and lower suggest severe fatigue. While additional research is required to clarify the relationship (8), it is hypothesized that scores of 4-7 may indicate performance impairment and that scores of 3 or less very likely indicate degraded performance on certain complex demanding tasks.

The 3-day premission crew-rest interval served as a baseline-data collection period. Self-estimates of subjective fatigue were collected at 0900, 1300, and 1700 each baseline day. A sleep survey was completed at 0900 each day. Prior to departing home station, fatigue responses were collected from both crews during preflight planning. Preflight activities occurred in the middle of the night for the 32- and 56-hour missions and at midday for the 44-hour missions. During the missions, fatigue data were collected about every 4 hours from the on-duty crew. When off duty, crewmen were not awakened for purposes of data collection. However, safety regulations required everyone on board to be seated during takeoffs, landings, and aerial refuelings. Parachutes were donned during aerial refuelings. A continuous record of sleep times was maintained on each crewman throughout the mission. All missions were intentionally scheduled for completion during late-morning home station time, a goal that was met for all completed missions. This time alignment permitted direct comparison of cumulative fatigue and subsequent recovery among the mission profiles. The day of mission completion was defined as recovery day 0. The last in-flight data were collected on recovery day 0 at 0900-1000 home-base time, about 1 hour prior to the final approach and landing. Recovery data were collected at 1300 and 1700 on the day of mission completion (recovery day 0) and at 0900, 1300, and 1700 on the next 3 days (recovery days 1, 2, and 3).

The 44-hour missions also served to evaluate the feasibilty of resting TAC crewmembers onboard aircraft during extended deployments. During the initial leg from Travis AFB to Clark AB, Philippines, two F-4 crews slept and lounged in a Venterior kit located in the C-5A cargo hold. The Venterior kit was furnished with a latrine and galley and comfortably housed the four F-4 crewmen, a TAC flight surgeon, and a supporting loadmaster. The TAC flight

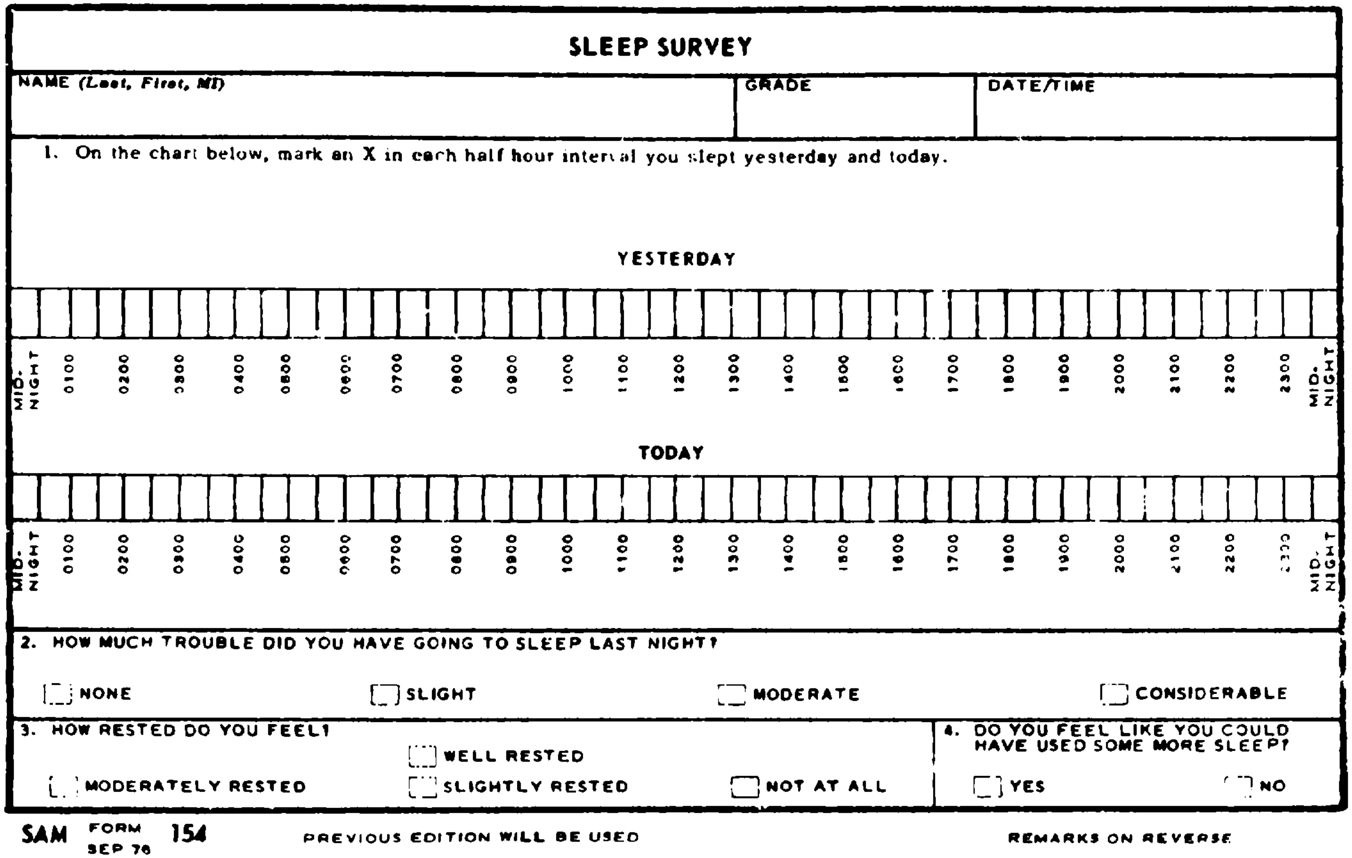

Figure 1. SAM Form 154: Sleep Survey.

NAME AND GRADE | TIME/DATE

INSTRUCTIONS: Make one and only one (✓) for each of the ten items. Think carefully about how you feel *RIGHT NOW*.

STATEMENT	BETTER THAN	SAME AS	WORSE THAN
1. VERY LIVELY			
2. EXTREMELY TIRED			
3. QUITE FRESH			
4. SLIGHTLY POOPED			
5. EXTREMELY PEPPY			
6. SOMEWHAT FRESH			
7. PETERED OUT			
8. VERY REFRESHED			
9. FAIRLY WELL POOPED			
10. READY TO DROP			

PREVIOUS EDITION WILL BE USED

SAM FORM 136
SEP 71

SUBJECTIVE FATIGUE CHECKCARD

Figure 2. SAM Form 136: Subjective Fatigue Checkcard.

surgeon accompanied the F-4 crewmen and assisted in documenting their activities and collecting data. Subjective fatigue data were collected on a schedule similar to that of the MAC crews. One F-4 crew was allowed to always sleep in bunks, the other only in airliner passenger seats. They determined their own sleep schedules, but were required to be seated during takeoffs, landings, and refuelings. Within a few hours after arrival at Clark AB, the F-4 crews were given a simulator check ride. Crew performance, coordination, and response to selected emergency procedures were evaluated by a TAC flight examiner and compared with a simulator evaluation conducted a few days before departure from Travis AFB. The F-4 crews remained at Clark AB for 3 days.

RESULTS

Data from the loadmasters were omitted from all analyses because cargo and passengers were excluded on these test missions. Some minor and a few major variations in itinerary occurred during the missions. Five of the six missions were successfully completed. The second 44-hour scenario was aborted 15 hours into the mission because of mechanical problems which forced an unscheduled landing in Guam. The first 56-hour mission made an unscheduled initial stop at Hickam AFB, Hawaii, cancelled the scheduled Clark AB stop, and proceeded for a successful flight. Summaries of key mission events are presented in Figure 3 for the five successful missions.

To evaluate the fatigue present at the end of each completed mission, two statistical analyses were made on the data from each mission.

Analysis A: Comparisons were made between the average 0900/baseline fatigue scores and the final (approximately 1000) in-flight score reported just prior to mission completion.

Analysis B: Comparisons were made between the average fatigue scores reported at 1300 and 1700 during baseline versus the scores reported at 1300 and 1700 on the day of return (recovery day 0) to home station.

Rate and pattern of recovery after each mission were evaluated by two additional analyses.

Analysis C: Average fatigue scores reported at 0900, 1300, and 1700 on recovery day 1 were compared with the average scores reported for the same times during baseline.

Analysis D: Fatigue scores reported across recovery days 1, 2, and 3 were compared with each other.

In each of these four analyses, the factor of primary interest was "day" and its interactions with the factors of "crew" and "time," since a change from baseline would be expected to reflect fatigue due to mission requirements.

Three statistical analyses were performed on the fatigue scores reported during each mission to determine whether there were differences in response between the two crews and within each crew.

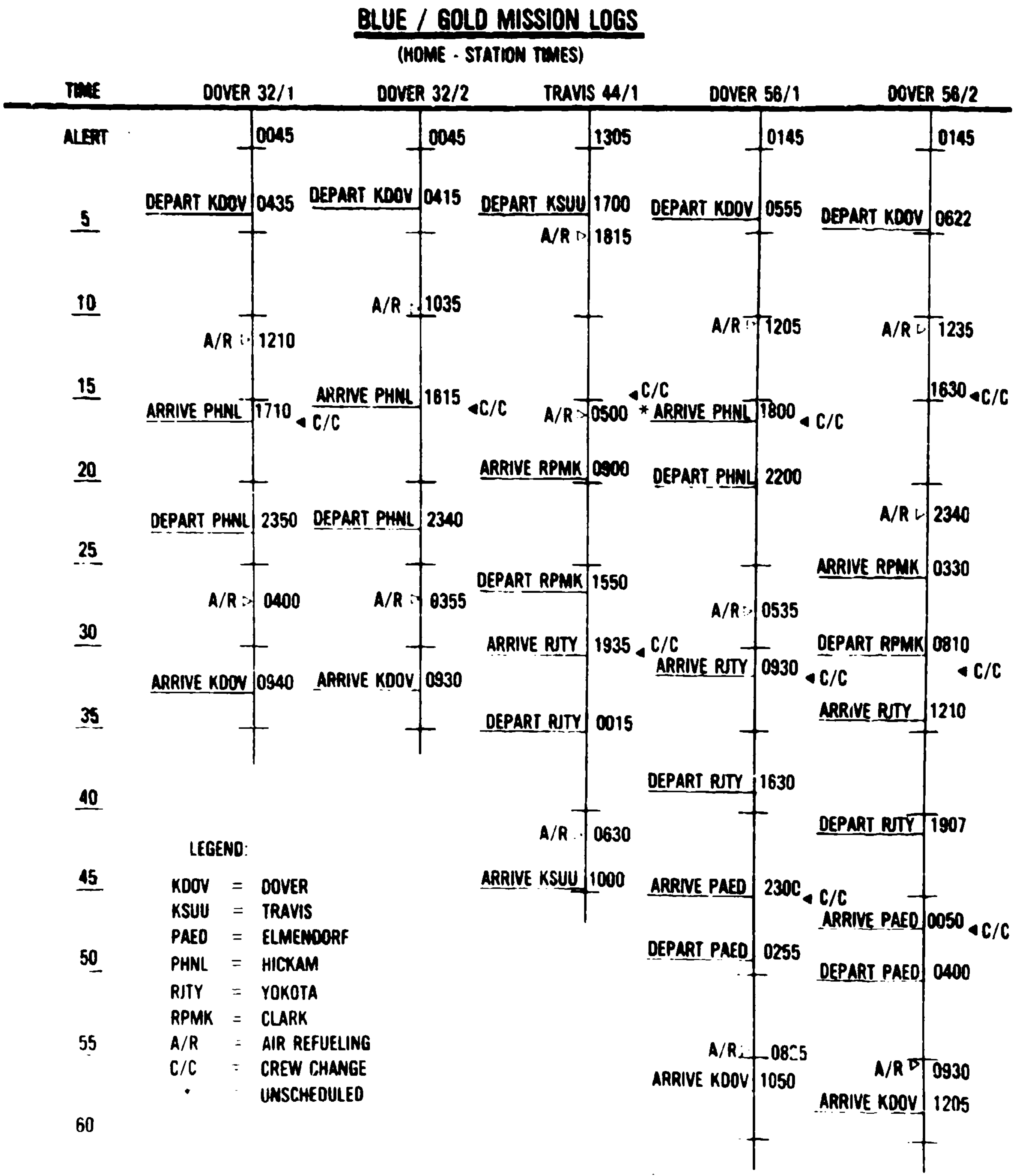

Figure 3. Blue/Gold mission logs.

Analysis E: Fatigue scores reported by Blue and Gold crews after being on duty for 16 hours were compared.

Analysis F: Fatigue scores reported by Blue and Gold crews at the end of their final duty periods were compared.

Analysis G: For the longer missions, comparisons were made within each crew between fatigue scores reported upon completion of the first and the second duty periods.

All fatigue scores submitted to analyses E, F, and G were adjusted for baseline by subtracting the appropriate mean baseline values prior to analysis. It was not always possible to use a baseline time that could be considered optimal to adjust the mission data. Several of the adjustments made to scores for the Blue crews were out of alignment, some by as much as 5 hours. For the 44-hour mission, no appropriate baseline values were available to adjust the 16-hour fatigue scores for the Blue crew; therefore, the analysis of fatigue scores after 16 hours on duty was not performed for this mission. The final on-duty period comparison was made for all five missions; for the 32-hour missions, this was the same as the "after 16 hours on duty" comparison.

Two statistical comparisons were made on the sleep data from each mission. The average number of hours slept per night during baseline was compared with the average hours slept during the first 24 hours at home. Trends in postmission recovery were determined by comparing the hours slept on each of the 3 recovery nights.

Based on this background of the statistical tests performed on fatigue and sleep data, a summary of the significant ($p \leq .05$) findings for each of the five missions will be presented next. While reviewing the summary statements, the reader may refer to Table 1 and Figure 4 for mean subjective fatigue scores reported during baseline and recovery days, to Table 2 and Figure 5 for mean fatigue scores reported in-flight, and to Table 3 for average hours slept during baseline and recovery.

Mission 32/1 (first 32-hour mission)--This was a 2-leg mission, with the Blue crew on duty going out and the Gold crew on duty during the return leg. Compared to the appropriate mean baseline fatigue scores, overall decreases in fatigue scores (indicating increased feelings of fatigue) were reported by both crews just prior to mission completion ($p=.003$, Analysis A), for the balance of recovery day 0 ($p=.012$, Analysis B), and on recovery day 1 ($p=.027$, Analysis C). For the two crews combined, feelings of fatigue diminished from recovery day 1 to recovery day 3 ($p=.021$, Analysis D). Overall, fatigue scores were significantly higher (less fatigue; $p=.026$, Analysis D) for the Blue crew than the Gold across recovery days 1-3. Both crews reported similar levels of severe fatigue at the end of their duty periods. The mean hours slept by both crews increased significantly ($p=.003$) during the first 24 hours of recovery, with a return to baseline sleep levels on recovery days 2 and 3. The difference in the hours slept among the recovery days was significant ($p<.001$).

TABLE 1. MEAN SUBJECTIVE FATIGUE SCORES DURING BASELINE AND ON RECOVERY DAYS 0, 1, 2, AND 3

Mission	Crew	Time	Baseline	Day 0	Day 1	Day 2	Day 3
32/1	Blue	0900	14.1	10.8	12.6	14.2	15.0
		1300	14.7	8.8	15.4	15.4	14.4
		1700	12.7	9.8	9.6	14.0	14.0
	Gold	0900	15.4	6.4	11.6	12.4	14.2
		1300	13.4	6.8	10.6	12.1	13.2
		1700	12.3	7.0	9.4	10.4	10.8
32/2	Blue	0900	13.2	10.6	13.4	12.2	14.6
		1300	14.2	10.2	13.6	13.9	14.8
		1700	12.1	10.8	14.0	14.5	14.7
	Gold	0900	12.3	5.2	10.8	11.2	13.2
		1300	13.3	3.4	11.0	11.4	12.0
		1700	10.5	6.0	9.6	9.8	10.6
44/1	Blue	0900	12.1	7.4	11.8	13.4	13.0
		1300	12.0	-	13.2	11.8	12.2
		1700	11.5	-	12.6	11.8	11.4
	Gold	0900	14.3	13.2	13.4	15.6	13.6
		1300	13.6	-	12.6	11.8	13.3
		1700	11.6	-	11.4	11.2	10.2
56/1	Blue	0900	13.5	6.6	13.0	14.4	14.6
		1300	13.3	3.8	11.6	13.6	14.0
		1700	11.8	6.6	12.4	11.2	12.0
	Gold	0900	11.7	5.6	9.6	10.4	9.8
		1300	14.5	1.6	12.4	11.6	14.0
		1700	12.5	2.8	11.0	13.4	10.0
56/2	Blue	0900	13.2	9.2	13.2	12.6	10.7
		1300	12.7	5.8	12.7	11.8	11.4
		1700	11.5	8.6	11.8	10.4	10.2
	Gold	0900	13.5	8.6	8.6	13.4	11.0
		1300	12.7	6.4	9.6	11.6	11.2
		1700	10.0	5.8	6.8	8.8	9.2

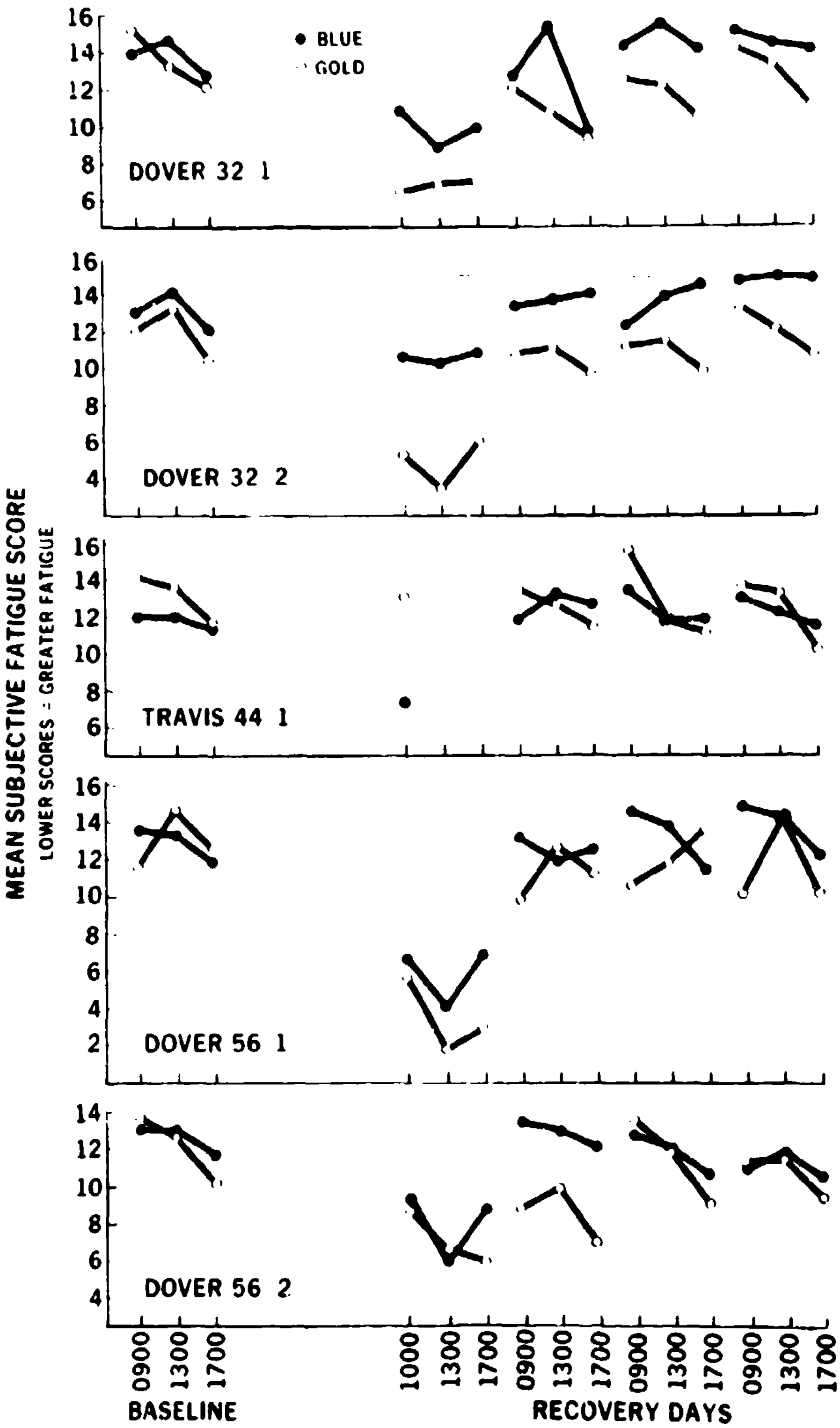

Figure 4. Mean subjective fatigue scores before (baseline) and after (recovery) each Blue/Gold mission.

TABLE 2. MEAN IN-FLIGHT SUBJECTIVE FATIGUE SCORES* AT PREFLIGHT, CREW SHIFT CHANGES, AND MISSION COMPLETION

Mission	Crew	Preflight	16-Hr	32-Hr	44-Hr	48-Hr	56-Hr
32/1	*(time)*	*(0200)*	*(1700)*	*(1000)*			
	Blue	12.5	$\underline{6.0}$	10.8	-	-	-
	Gold	11.2	10.6	$\underline{6.4}$	-	-	-
32/2	*(time)*	*(0300)*	*(1700)*	*(1000)*			
	Blue	12.8	$\underline{11.0}$	10.6	-	-	-
	Gold	11.2	10.0	$\underline{5.2}$	-	-	-
44/1	*(time)*	*(1400)*	*(0400)*	*(1900)*	*(1000)*		
	Blue	13.2	$\underline{8.4}$	11.8	$\underline{7.4}$	-	-
	Gold	11.8	10.2	$\underline{8.6}$	13.2	-	-
56/1	*(time)*	*(0500)*	*(1900)*	*(0900)*		*(2300)*	*(1000)*
	Blue	11.2	$\underline{8.8}$	11.2	-	$\underline{9.4}$	6.6
	Gold	6.8	9.8	$\underline{4.6}$	-	10.2	$\underline{5.6}$
56/2	*(time)*	*(0500)*	*(1700)*	*(0800)*		*(0100)*	*(1000)*
	Blue	10.2	$\underline{8.8}$	8.6	-	$\underline{7.0}$	9.2
	Gold	8.0	11.0	$\underline{4.2}$	-	8.2	$\underline{8.6}$

---

*Scores reported at the end of a duty period are underlined; scores reported at the end of a rest period are not underlined. In general, scores of 12 and higher indicate feelings of alertness, scores from 11 down to 8 indicate moderate fatigue, and scores of 7 and lower suggest severe fatigue.

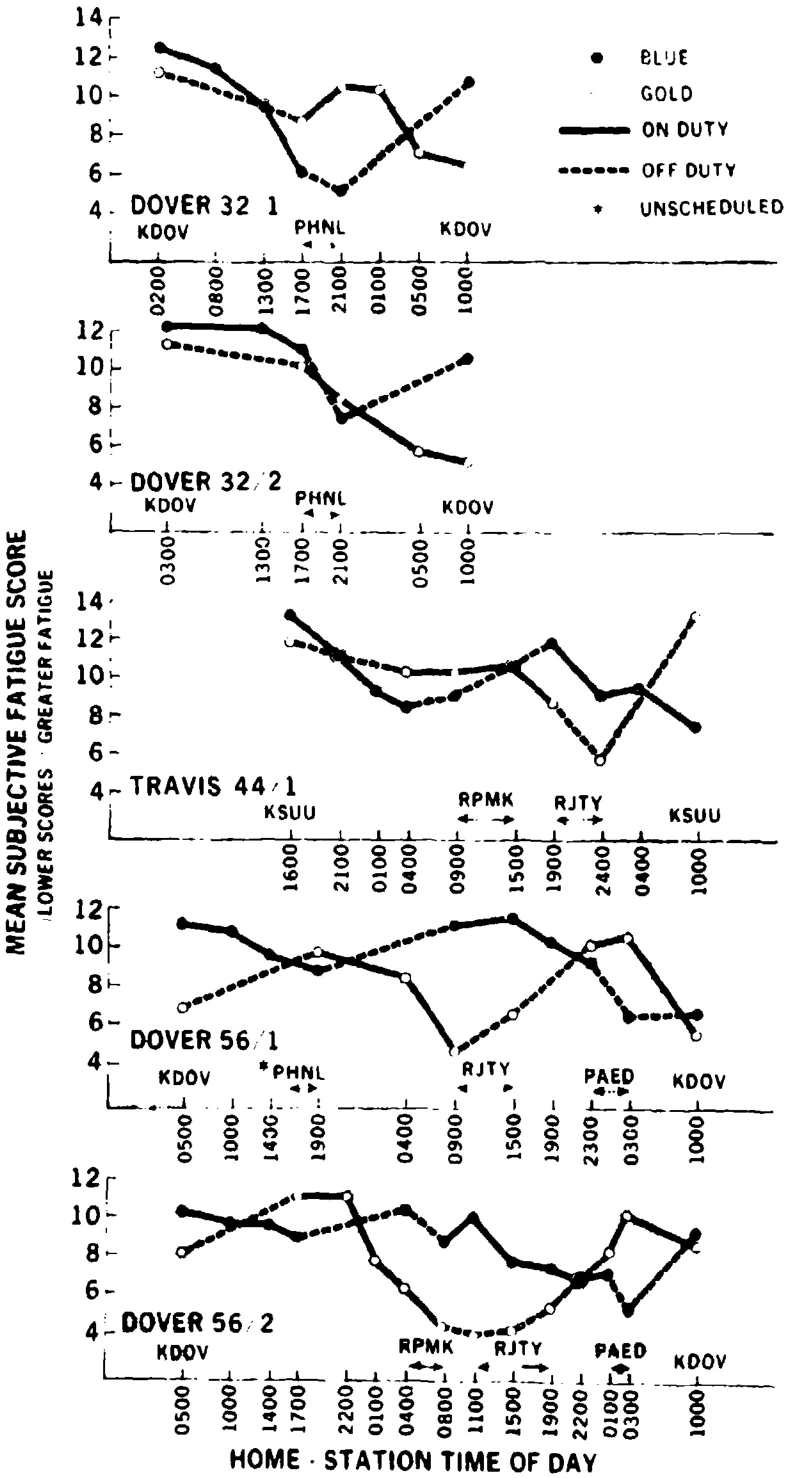

Figure 5. Mean subjective fatigue scores during each Blue/Gold mission.

TABLE 3. MEAN HOURS SLEPT DAILY DURING BASELINE AND ON RECOVERY DAYS 1, 2, AND 3

Mission	Crew	Baseline	Day 1	Day 2	Day 3
32/1	Blue	7.8	10.6	7.6	7.8
	Gold	7.6	10.9	6.8	8.6
32/2	Blue	9.3	9.0	8.9	8.3
	Gold	8.5	14.6	8.5	8.2
44/1	Blue	8.5	12.3	9.2	8.1
	Gold	7.7	8.9	7.5	7.6
56/1	Blue	7.6	10.8	7.8	8.0
	Gold	7.2	10.7	8.3	6.8
56/2	Blue	7.5	9.9	8.1	6.3
	Gold	8.1	11.3	8.2	7.2

Mission 32/2--Fatigue scores were depressed for both crews upon mission termination, but much more for the Gold crew than the Blue ($p=.035$, Analysis A). Average fatigue scores for the two crews combined were significantly lower ($p=.001$, Analysis B) at 1300 and 1700 on recovery day 0 than during baseline (a relatively greater decrease for the Gold crew was not statistically significant). The Gold crew was much more fatigued at the end of their duty period than was the Blue crew ($p=.012$, Analysis E). During the first 24 hours of recovery, the Blue crew slept about the same number of hours as they averaged on each baseline night, but the Gold crew slept a great deal more than during baseline ($p=.014$). Analysis of the hours slept across recovery days 1-3 again detected the large number of hours slept by the Gold crew on the first night. In this case, a significant ($p<.001$) crew x day interaction resulted, as the two crews slept very similar and typical numbers of hours on recovery nights 2 and 3.

Mission 44/1--This was a 3-leg mission. The Blue crew was on duty during the first and last thirds of the mission; the Gold crew was on duty during the midportion. The three legs did not align temporally with the three duty periods. At mission termination, the Blue crew was significantly ($p=.028$, Analysis A) more fatigued than the Gold crew, which reported feeling fresh and alert. Missing data prohibited the statistical comparison of baseline versus recovery-day-0 fatigue scores at 1300 and 1700. However, the alleviation of fatigue across recovery days 1, 2, and 3 is apparent in Table 1 and Figure 4. Both crews reported increased hours slept for the first night of recovery, but the increase was much greater ($p=.009$) for the Blue than the Gold crew. For the two crews combined, the average hours slept each recovery night differed significantly ($p=.004$), with the amount of sleep on nights 2 and 3 being similar to average baseline values.

The four TAC crewmen housed in the Venterior kit reported 7.5-9.5 hours of sleep during the 17-hour leg to Clark AB. Although data collection was incomplete, no significant levels of subjective fatigue were reported. The TAC crews arrived feeling alert and confident of their capabilities. Their simulator performance verified these subjective reports: the flight examiner reported no deterioration during the postmission check. Mild insomnia was reported during the first day or two of adjusting to the 8-hour time zone change, but no complaints of fatigue during the daylight hours.

Mission 56/1--The 56-hour missions included four legs. Each crew performed two duty periods, with no correspondence between legs and duty periods. The second Gold crew-duty periods of both 56-hour missions were only 10-12 hours long, not 16. Both 56/1 crews were considerably fatigued at mission termination ($p=.008$, Analysis A). At 1300 and 1700 on recovery day 0, both crews reported fatigue scores lower than baseline scores ($p<.001$, Analysis B), but the Gold crew's scores suffered a larger decrement than the Blue ($p=.038$, Analysis B). Overall during recovery days 1-3, mean fatigue was significantly greater ($p=.010$, Analysis D) for the Gold crew than the Blue. The hours slept during the first 24 hours of recovery were notably greater ($p<.001$) than baseline values for both crews. The hours slept on the second and third recovery nights were similar to baseline values, resulting in a significant ($p<.001$) difference in hours slept among the 3 recovery nights.

Mission 56/2--As in mission 56/1, both crews were fatigued at mission completion ($p=.016$, Analysis A) and at 1300 and 1700 on recovery day 0 ($p=.004$, Analysis B). The Gold crew was more fatigued after 16 hours on duty than was the Blue crew ($p=.004$, Analysis E). The only significant difference between first and second work periods occurred on this mission for the Gold crew, which was less fatigued at the end of the abbreviated second duty period than at the end of the first duty period ($p=.039$, Analysis G). Both crews slept significantly more hours on the first recovery night than during baseline ($p=.020$). Hours slept returned to normal levels on recovery nights 2 and 3, resulting in a significant ($p=.001$) difference among recovery nights.

DISCUSSION

Summarizing the five completed missions, the subjective fatigue experienced by the double crews was closely related to the mission schedules. The crews were well rested at the start of each mission, averaging a typical 7-8 hours of sleep per night during the 3 baseline days. Between the last complete baseline night and mission alert for early-morning preflight planning and departure, the crews assigned to the 32- and 56-hour missions acquired a few hours sleep. Prior to the afternoon departure of the 44-hour mission, essentially no sleep was reported between the last baseline night and mission alert. Mean fatigue scores decreased (indicating increased fatigue) in all but one (Gold 56/2 second duty period) of the 15 duty periods that occurred during the five missions (Table 2). Moderate levels of fatigue were reported at the end of seven duty periods, and severe fatigue at the end of eight. The severity of the mean fatigue reported at the end of a duty period tended to be related to the number of nights of sleep disruption, based on home-station

time. The four Dover mission-schedules (32- and 56-hour missions) required the Gold crews to be on duty when they would have normally been sleeping and to sleep when they would have normally been awake. The Travis mission-schedule (44-hour mission) had a similar wake/sleep reversal effect on the Blue crew. These scheduling effects are emphasized in Figure 5 by the stippling of the home-station sleep periods. Six of the eight mean scores reflecting severe fatigue at the end of a duty period were reported by the Dover Gold and Travis Blue crews after they had experienced 2 or more nights of sleep disruption--again, in relation to home-station time. The mean fatigue scores reported at the completion of each duty period and identified in Table 2 are presented again, with their associated nights of sleep disruption, in Table 4. Substantiation of this possible relationship would require systematic manipulation of the elapsed time into mission and the number of nights of sleep disruption, factors that were confounded in the Blue/Gold missions.

TABLE 4. MEAN FATIGUE SCORES AND ASSOCIATED NIGHTS OF SLEEP DISRUPTION AT THE COMPLETION OF EACH DUTY PERIOD

Mission	Crew	Duty Period	
		First	Second
32/1	Blue	6.0 (1)*	-
	Gold	6.4 (2)	-
32/2	Blue	11.0 (1)	-
	Gold	5.2 (2)	-
44/1	Blue	8.4 (1)	7.4 (2)
	Gold	8.6 (1)	-
56/1	Blue	8.8 (1)	9.4 (1)
	Gold	4.6 (2)	5.6 (3)
56/2	Blue	8.8 (1)	7.0 (1)
	Gold	4.2 (2)	8.6 (3)

*nights of sleep disruption.

The Blue and the Gold crews reported averages of 5-7 hours of fragmented and fitful sleep per 16-hour rest period, and they complained about the noise (83 dBA) and vibration levels in the troop compartment. However, some alleviation of fatigue resulted while off duty, as mean fatigue scores usually improved by the end of each rest period that followed a duty period (Table 2). Occasionally, resting crewmen had to be awakened in preparation for aerial refuelings, landings, or takeoffs. These interruptions of sleep were received with considerable annoyance. On the 56-hour missions, the Gold crews acquired several hours of sleep during their second rest period in the troop compartment while on the ground at night at Yokota AFB, Japan. The circumstances provided a good sleeping environment: little or no flightline noise and comfortable temperatures. As a result, the Gold crews reported for their second duty period much more rested than when they entered crew rest. At other times, onboard rest while on the ground was severely hampered by flightline noise, uncomfortable temperatures, and the activities of maintenance crews. Under these conditions, resting crewmembers benefited more by leaving the aircraft and eating, cleaning up, or simply moving about. During intervals of reduced workload, on-duty crewmen would occasionally obtain 1 or 2 hours of sleep in the C-5A flight-deck motel facility.

At the end of the 32- and 44-hour missions, the crews last on duty reported greater fatigue than the resting crews. At the end of the 56-hour missions, the two crews showed little difference: both resting and working crews reported moderate (mission 56/2) to considerable (mission 56/1) fatigue. The mean subjective fatigue scores reported at mission completion (0900-1000) and later the same day (1300 and 1700), after entering postmission crew rest, were considerably lower than those reported during baseline. Eight of the 10 crews reported a 30% or greater increase in hours slept during the first 24 hours of recovery (Table 3). The subjective fatigue scores reported on recovery days 1, 2, and 3 and the hours slept during the second and third nights of recovery seldom differed from those reported during baseline.

These findings concur with those previously reported by Atkinson et al. (1), Harris et al. (4), and Hartman et al. (5), who also evaluated fatigue and sleep patterns in double crews flying strategic airlift missions. Aerial refuelings were not a factor in their studies. The Harris and Hartman studies used the same fatigue and sleep surveys used in this study. Although their analyses of fatigue scores did not evaluate on-duty versus off-duty status, similar increases in fatigue occurred for both 4/4- and 16/16-hour work/rest schedules. The work/rest cycles were determined to not be a primary variable for operational concern, but to impact at a secondary level by constraining sleep and rest periods. Atkinson et al. recommended a 12/12 work/rest schedule. These previous efforts all reported substantial increases in hours slept on the initial day of postmission recovery and found complete recovery to require 3-5 days in some instances.

Deployment of TAC aircrews with in-flight crew rest using the Venterior kit aboard MAC aircraft was very effective. The only complaints were related to the very low humidity and to sleeping in reclined passenger seats. The mission schedule was favorable for the TAC crews. Following the late afternoon departure from Travis AFB and an early refueling, it was the TAC

crews' normal time to retire for the evening. They acquired a good night's sleep, awoke refreshed, and performed well in the simulator at Clark AB. Thus, the deployed crewmen could fulfill a normal duty day. The TAC crewmen participating in this mission readily adjusted to the new time zone, but they had no rigid schedule or workload to perform. The ability of TAC crews, deployed with airborne crew rest, to perform repetitive missions under a sortie surge operation cannot be estimated from this initial test.

RECOMMENDATIONS

The MAC test plan addressed five medical objectives.

1. Identify and analyze psychophysiologic stresses (sleep [illegible] fatigue buildup, circadian rhythm desynchronization).

Whether on crew rest or duty, the demands of the [illegible] the aircraft environment, and the fragmented opportunities for sleep resulted in substantial fatigue as a mission progressed. The sleep acquired in the troop compartment was of poor quality but did allow some amelioration of fatigue and, therefore, continuation of the extended missions. In some instances, reversal of sleep/wake cycles may have exacerbated crew fatigue.

2. Determine maximum flying and crew duty-day limitations.

While there is no optimal work/rest schedule for double-crew missions, 16-hour intervals are generally too long for either work or rest periods. More frequent rotation, on an 8-12 hour basis, would result in less fatigue at the end of a duty period and still provide ample time for rest. Every opportunity should be taken to tailor crew schedules to the mission profile. A shift change between crews should not occur during the hour preceding a takeoff, landing, or aerial-refueling operation. Within this framework, double-crew aerial-refueled missions of 40-48 hours are feasible and safe.

3. Determine home-station predeparture and postmission crew rest requirements.

Current home-station C-5A predeparture rules are appropriate. On completion of double-crew aerial-refueled missions, both crews should remain in postmission recovery a minimum of 48 hours, including 2 nights of uninterrupted normal sleep (2200-0600 local time).

4. Determine minimum recovery period for repetitive missions.

The test plan did not permit direct evaluation of crew fatigue associated with repetitive missions. The fatigue and sleep data indicate, however, that crews flying back-to-back double-crew aerial-refueled missions should have postmission crew rest of at least 72 hours, including 3 nights of uninterrupted normal sleep (2200-0600).

5. Evaluate the concept of resting TAC crews in a live-aboard concept on C-5A extended missions.

Under the conditions of the mission tested, the C-5A deployment of onboard resting TAC crews was effective. The Venterior kit provided the TAC crews with an exceptional rest facility and offered a sleeping environment much better than that used in the troop compartment by the MAC crewmen. After a 17-hour nonstop deployment, the TAC crews were rested and operationally capable of performing a mission. However, the ability of the TAC crews to effectively perform repeated missions for several days (a sortie surge) following deployment was not evaluated.

REFERENCES

1. Atkinson, D. W., R. G. Borland, and A. N. Nicholson. Double-crew continuous flying operations: A study of aircrew sleep patterns. Aerospace Med 41:1121-1126 (1970).

2. Hale, H. B., B. O. Hartman, D. A. Harris, R. E. Miranda, and E. W. Williams. Physiologic cost of prolonged double-crew flights in C-5 aircraft. Aerospace Med 44:999-1008 (1973).

3. Hale, H. B., B. O. Hartman, D. A. Harris, E. W. Williams, R. E. Miranda, J. M. Hosenfeld, and B. N. Smith. Physiologic stress during 50-hour double-crew missions in C-141 aircraft. Aerospace Med 43:293-299 (1972).

4. Harris, D. A., G. V. Pegram, and B. O. Hartman. Performance and fatigue in experimental double-crew transport missions. Aerospace Med 42:980-986 (1971).

5. Hartman, B. O., H. B. Hale, D. A. Harris, and J. F. Sanford III. Psychobiologic aspects of double-crew long-duration missions in C-5 aircraft. Aerospace Med 45:1149-1154 (1974).

6. MAC Operational Test and Evaluation Final Report 15-13-77, Blue and Gold Concept. Scott AFB, Ill., Apr 1978.

7. Pearson, R. G., and G. E. Byars, Jr. The development and validation of a checklist for measuring subjective fatigue. SAM-TR-56-115, Dec 1956.

8. Perelli, L. P. Fatigue stressors in simulated long-duration flight: Effects on performance, information processing, subjective fatigue, and physiological cost. SAM-TR-80-49, Dec 1980.